Simulation and Optimization of the Temperature and Humidity Independent Control Showcase

Huabo Hou [1] Master
Likui Yu [1,2] Associate professor
Xiongfeng Wan [1] Master
Huanxin Chen [2] Professor

School of Energy Science and Engineering, Central South University [1]
Changsha P. R. China, 410083

Institute of Energy and Power, Huazhong University of Science and Technology [2]
Wuhan P. R. China, 430074

huabohou@163.com yulikui@sina.com xiongfengwan@gmail.com hxchen@mail.csu.edu.cn

Abstract: A new kind of showcase with temperature and humidity independent control is introduced in this paper to reduce the energy consumption of the showcase's air-conditioning system. Computational Fluid Dynamics was employed to investigate this new showcase's temperature field; more attention was focused on the effects of inlet's temperature and velocity. It is found that inlet temperature is the key factor affecting the temperature field. The lower the inlet temperature is, the less the effect on the showcase is. It is also found that the inlet velocity's effect on the showcase's temperature field is little. However, to satisfy the cultural relics' preservation, the inlet velocity should be keep at a low value.

Key words: temperature and humidity independent control; radiant cooling panel; liquid desiccant; showcases; simulation; optimize

1. INTRODUCTION

Showcases are widely used because they are useful to display and protect: in fact they offer a protection against vandalism, robberies and any direct damage that could come from visitors. In addition, often, they are installed with HVAC systems for conservation, with the hope that they work as a good 'guard' against environment attacks due to microclimate variations. During the last decade, utilizing the surface air cooler to cool and desiccate air in order to control the temperature and humidity in showcases is popular with the museum' caretakers and designers[1~6]. However, this method wastes so much energy that makes the operating charges of museum very high [7].

For reducing the energy consumption of the air-conditioning system, a new kind of showcase with the temperature and humidity independent control is introduced in this paper. In this showcase, its temperature is controlled by radiant cooling panel which is installed in the case [8], and the humidity is adjusted by centralized liquid desiccant system. It has been validated that the radiant cooling panel can make a 28% to 40% reduction in energy usage compared the conventional HVAC system [9], and the liquid desiccant system saves energy too.

This paper first presented the operating principle and work mode of the showcases particularly. Attention was then focused on the influence of the desiccant system's supply air temperature and velocity to the showcases interior temperature field and flow field. Meanwhile, the calculating model is developed to simulate and analyze the temperature field and flow field in showcases. Finally, several parameters are optimized to improve the showcases so that the radiant cooling panel and the desiccant system can be coupled well on the basis of calculating result.

2. TEMPERATURE AND HUMIDITY INDEPENDENT CONTROL SHOWCASE

The temperature and humidity independent control showcase is composed of three systems: temperature control unit, humidity control unit and humidity buffering unit. Fig. 1 shows the geometry and modules of the showcase schematically. From Fig. 1 we can see that the temperature control unit is the radiant cooling panel namely. In the radiant cooling panel, the pipes through which chilled water flows are disposed in parallel. The pipes lie close to the panel surfaces, and they cool the showcase via natural convection and radiation heat transfer [8]. To make the interior humidity of the showcase fall to a fixed level, the centralized liquid desiccant system is utilized [10]. The air which is dried by the liquid desiccant equipment is supplied into the showcase through duct. When the inside humidity is lowered to a design value, the system will stop operating. After this, the humidity is maintained by the buffering unit which contains moisture-conditioned materials [5]. Therefore, the centralized liquid desiccant system's runtime isn't long, it just runs at the beginning to change the interior humidity, and it runs at the situation that the showcase need it supply air to maintain interior positive pressure too.

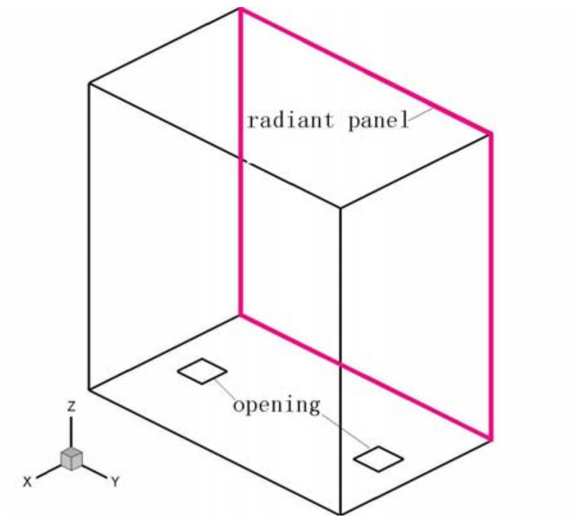

Fig.1 Configurations of showcase

In previous studies, the radiant cooling panel has been considered to be an energy conservation system; the liquid desiccant system has been report that it can save energy and filtrate some contaminations; and the moisture-conditioned material has been considered to be an effective tool for the humidity control. However, in this temperature and humidity independent control showcase the centralized liquid desiccant system supply air may influence the inside temperature. To optimize the system, the influence on the temperature must be decrease to minimum level. So the numerical simulation analysis method was employed to optimize the showcase's configuration in this paper.

3. NUMERICAL ANALYSIS

3.1 Physical model

The physical models and the coordinate systems of this new kind showcase have been schematically shown in Fig. 1. Like the familiar showcase, most surfaces of the new showcase are glass panel except bottom and the side that close to wall so that the cultural relics can be seen from several directions by visitor.

The dimensions of the showcase are 0.6m×1m×1m, and there are two openings local on the panel of the showcase, their sizes are 0.1m×0.1m respectively.

3.2 Numerical method

In order to simplify the problems, some presuppositions are listed as follows:

- The flow is steady and incompressible;
- All panels are black;
- The air contained in the box is assumed to be absorbing and emitting;
- Ignore the effect of culture relics in the showcase.

Since the temperature difference inside is a main force for the buoyancy flows, the Boussinesq approximation, which relates density change with temperature difference, was employed. Standard k-ε model was adopted as the turbulent model and the standard wall functions are needed. The radiation transfer in the new showcase was modeled using DO model.

The simulations use the finite volume differencing scheme and SIMPLE algorithm [11]. The third-order QUICK differencing scheme [12] was used to evaluate the convection terms, the energy equation and the turbulent transport equation. Structured Cartesian meshes are used to discretize the cases. Finer grids were used for more critical areas such as openings and the region near to the panel. The numerical calculation was performed using the Computational Fluid Dynamics package Fluent, version 6.1.

3.3 Boundary conditions

As be referred before, a majority of the showcase's panels are made of glass. The showcase interior environment changes easily due to the exterior temperature variety. Therefore, the glass panel's wall temperature was fixed as the exterior temperature directly. Here we consider the temperature of the glass panel as 27 . Radiant cooling panel is a low temperature panel, whose temperature is 7 . And the bottom panel was considered to be adiabatic. Because the boundary conditions for the inlet are variety in different cases in order to investigate its influence on the temperature of showcase, they are listed the following text in detail.

4. RESULTS AND DISCUSSION

Temperature in exhibition and storing areas of collections of cultural character is one of the important factors of deterioration. Inhomogeneous temperature distribution inside showcase may lead to accelerate the deterioration of the cultural relics. Wilson suggested that a constant temperature with the rage from deep-freeze to about 18 would be suitable for storage of paper records [13]. The value of 18 then was taken as a criterion to judge the showcase temperature distribution.

Fig. 2 shows the temperature nephograms of y=0.15m cross sections of the showcase that under two conditions: centralized liquid desiccant system operating period (with opening); and the other is the system not operating (without opening). From the figure we can see that the temperature nephograms of the showcase between the two conditions are different remarkably. When the desiccant system doesn't operate, i.e. the opening is shutting, the temperature field control by natural convection and radiation heat transfer, so it distributes regularly, likes stratified. In the figure, the temperature isothermals that below 18 are almost vertical, especially the T=18 .This kind of temperature distribution characteristic is fit for preservation of flat cultural relics, such as papery material. However, when the desiccant system is running, the temperature field inside of the showcase is dominated by forced convection, so the temperature's distribution that around opening is anomalistic. To preserve the culture relics well, the opening's impact on the temperature should be reduced at least level. And the temperature field is mostly affected by the opening's inlet temperature and inlet velocity, which will be discussed later.

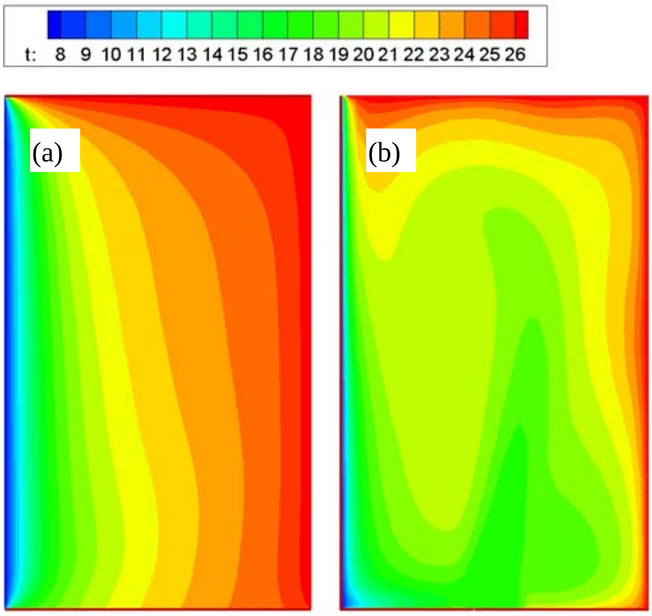

Fig.2 Temperature nephograms of *y*=0.15m cross sections

(a) without opening; (b) with opening

4.1 effect of inlet temperature

To study the effect of inlet temperature alone, inlet velocity is kept as 1m/s, and the inlet temperature is changed from 7 to 27 .Fig.3 shows the variations of isotherms of y=0.15m cross sections of the showcase at different inlet temperature. When the inlet temperature is very low, such as T=7 , the temperature gradient is very precipitous near to the opening, and the area of the zone that below T=18 is increased due to the low temperature flow. However, the temperature distribution is anomalous in this zone. And the left upside zone is compressed by the flow, which is compared with Fig. 2a. As a result, the zone for preserving culture relics becomes smaller than the condition of opening shutting. When the inlet temperature increases, the temperature distribution is still anomalous, and the zone that below T=18 is more and more small.

Table 1lists the area of the zone that below T=18 on x=0.1m cross section. Because the T=18 isothermal in the y=0.15m cross sections of the showcase with opening shutting is nearly vertical, and it locate at x=0.1m, which can be seen from

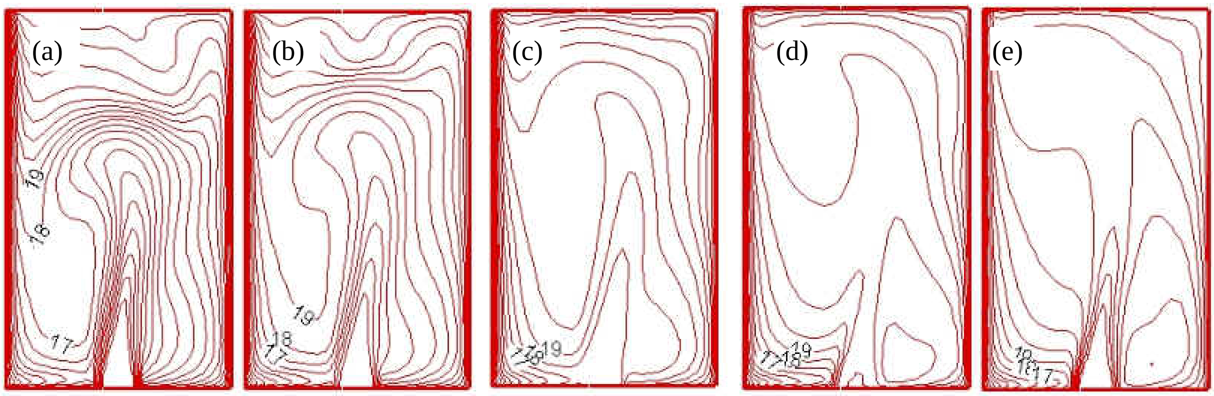

Fig.3 Isothermals of *x*-*z* cross section (*y*=0.15m)

(a) T=7 ; (b) T=12 ; (c) T=17 ; (d) T=22 ; (e) T=7

Tab.1 Area of the zone that below *T*=18 on *x*=0.1 cross section (m^2)

Inlet temperature( )	*No inlet*	*7*	*12*	*17*	*22*	*27*
Area (m^2)	0.453	0.229	0.099	0.063	0.049	0.045

Fig. 2a, we take the area of the zone that below *T*=18 on *x*=0.1m cross section as a criterion. From Table 1 we can find that the area is biggest when showcase's opening is shutting. When there is air supply into the showcase, the area decreases immediately, even when the inlet temperature equal to radiant cooling panel temperature. The area becomes smaller and smaller long with the inlet temperature's increasing, and it is below 0.1 m^2 except *T*=7 . Therefore, the temperature of the inlet is key infection factor for the showcase's interior temperature. To decrease the influence, we should reduce the inlet temperature to a low value.

4.2 effect of inlet velocity

To study the effect of inlet velocity alone, inlet temperature is kept as 17 , and the inlet velocity is changed from 0.1m/s to 2m/s. Fig.4 shows the variations of isotherms of *y*=0.15m cross sections of the showcase at different inlet velocity. When the velocity is very low, the heat transfer in the showcase is dominated by conduction and radiant heat transfer, and the flow just promotes the heat transfer. So the isothermals near the opening lean to right panel, and the low temperature zone that below 18 in the left part is decrease. As the velocity increases, the forced convection enhances gradually. When the velocity is 2m/s, it begins to hold the dominant status. And the inlet velocity is so large that the inlet flow can separate the temperature field likes cold air curtain, therefore, the heatsource from right panel's impact on the left panel is decreased. This may be good for the preserving, but it just exists near opening, so its effect is small for the whole showcase.

Table 2 lists the area of the zone that below *T*=18 on *x*=0.1m cross section. As be referred before, we still take the area of the zone that below *T*=18 on *x*=0.1m cross section as a criterion. Because of the high inlet temperature (*T*=17), all the area is below 0.1m^2, which is smaller than the condition that the opening is shutting. When the velocity increases, the area varies little. So the changes of the inlet velocity don't impact too much on the temperature field. However, the low velocity is needed customarily to protect the cultural relics well [14]. So the lower of the inlet velocity in the showcase, the better the environment is in it for the cultural relics.

5. CONCLUSIONS

In the present work, the temperature field of the temperature and humidity independent control showcases was investigated by numerical simulation. The efforts have been concentrated on the temperature and velocity of the inlet's impact on the showcase temperature field. Some simple conclusions are drawn as follows:

1) When the humidity of the showcase is

maintained by the buffering unit, the temperature distributes regularly. This kind of temperature

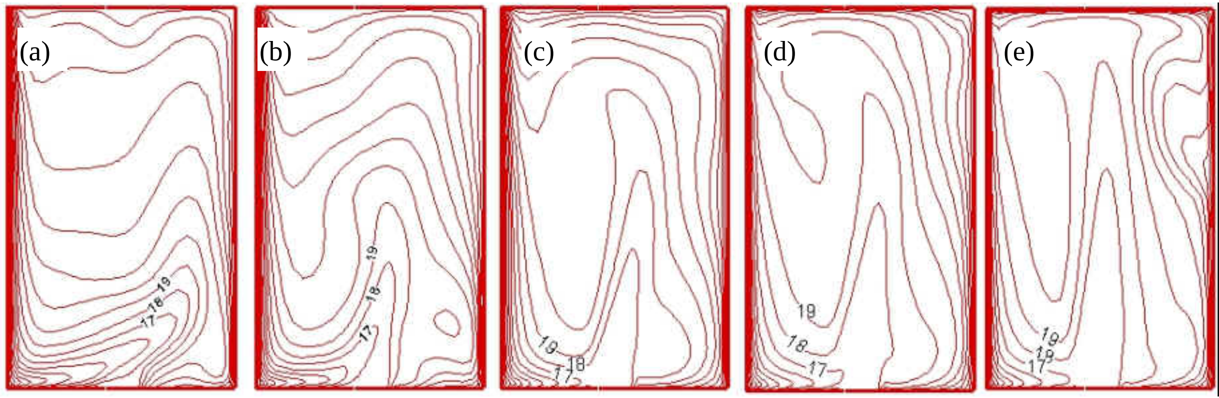

Fig.4 Isothermals of *x-z* cross section (*y*=0.15m)

(a) V=0.1m/s; (b) V=0.5m/s; (c) V=1m/s; (d) V=1.5m/s; (e) V=2m/s

Tab.2 Area of the zone that below *T*=18 on *x*=0.1 cross section (m^2)

Inlet velocity(m/s)	*0*	*0.1*	*0.5*	*1*	*1.5*	*2*
Area (m^2)	0.453	0.077	0.070	0.063	0.076	0.074

distribution characteristic is fit for preservation of flat cultural relics, such as papery material.

2) As the inlet temperature increases, the zone which is becoming to preserve cultural relics decreases gradually. To weaken the influence, we should reduce the inlet temperature to a low value.

3) The inlet velocity's effect is small for the whole showcase. But the low velocity is needed customarily to protect the cultural relics well. So we should keep the inlet velocity at a lower value in the showcase.

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